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Feasibility of Various NDE Techniques to Assess and Monitor Damage in Ceramic Composites at Elevated Temperatures

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Introduction and Summary of Previous Work

The research effort for this proposal was directed towards studying the feasibility of the acousto-ultrasonic (AU) NDE method with alternative nondestructive evaluation (NDE) tools for monitoring damage in ceramic composites at elevated temperatures. The AU or other alternative NDE techniques developed/evaluated in this project will be used as a tool to study the failure mechanisms of ceramic composites under dynamic (static and fatigue) loads at elevated temperatures.

This project was based on the successful completion of the past project (funded by the NASA HITEMP Project Office, 1993-1995) to develop AU as an NDE tool to monitor damage at room temperature under dynamic loads [4]. A listing of major findings and conclusions drawn are given below :

- The feasibility of the real-time acousto-ultrasonic (AU) technique to assess and monitor the damage state in SiC/CAS ceramic composites under dynamic loads, (quasi-static and fatigue loading) has been shown [1-7]. It was found that the real-time AU technique can monitor damage progression in ceramic composites subjected to quasi-static and fatigue loading without interrupting the mechanical loading test. The dynamics of damage mechanisms often are altered by interrupting a test for damage documentation by conventional NDE techniques. Hence, the development of the real-time AU technique can be considered a significant contribution to the NDE field in terms of quantifying damage development continuously and naturally throughout loading.

- Real-time AU was used for monitoring damage progression in unidirectional and cross-ply SiC/CAS ceramic composites subjected to quasi-static loads. The real-time AU technique detected the onset and saturation stress levels [2] for matrix cracking. The AU results were corroborated by in-situ optical microscope video recordings.

- The AU parameter is a good measure of initial integrity of the material studied here. The initial SWF (M0) shows an approximately linear correlation with the ultimate strength of unidirectional SiC/CAS ceramic composite. The higher the value of initial SWF (M0), the higher is the ultimate strength of unidirectional SiC/CAS ceramic composite [4].

- Real-time AU was used to monitor the progression of each damage mode occurring during mechanical tests. Real-time AU indicated the occurrence of almost 25% fiber breaks at saturation of matrix cracks in a unidirectional SiC/CAS ceramic composite. An etched unidirectional SiC/CAS sample (loaded till saturation of matrix cracks) verified and complemented the conclusions based on real-time AU data. This additional information regarding the sequence of occurrence of each damage mode has greatly added to our fundamental knowledge of the failure mechanisms of SiC/CAS-II ceramic composites subjected to quasi-static loads. The acousto-ultrasonic stress-strain response (AUSSR) models have been developed [5] to predict the stress-strain curve using real-time AU data and thereby help in studying the failure mechanisms of SiC/CAS ceramic composites.

The prediction of these models approximates the corresponding typical experimental curve. The basic damage mechanisms occurring during quasi-static tests are interpreted with the help of real-time AU data and supported by AUSSR models.

- The Weibull parameters (obtained from AU data,) α and β, can be used to predict the onset of large scale matrix cracking in ceramic composites. Our findings [4] show that the onset of matrix cracking should be used as the design stress for thermo-structural applications instead of the critical cracking stress obtained from the Budiansky, Hutchinson and Evans model.

- The real-time AU technique also monitors damage progression during fatigue [6,7]. Reduction in stiffness correlates with the change in the AU parameter at different stages of fatigue life. These results were complemented and verified by edge replica photographs.

- In addition, the research work also verifies the capability of the real-time AU technique to monitor micro-buckling, longitudinal splits and delaminations (damage modes associated with compression-fatigue) [7].

Present Results

The goals of the present short project were directed towards a continuing effort to develop an NDE tool to monitor damage at elevated temperature. The work performed was a continuation of the unfinished summer work performed at the Structural Integrity Branch, NASA Lewis Research Center, from July -August, 1995. The results presented here also include the work performed during the summer for clarity.

The first major task was to assemble a custom made oven, purchased from Instron, to fit around the specimen grips in the load frame. This work included setting up the oven on an Instron load frame, working with the temperature controller to obtain its correct functioning and properly configuring the temperature controller/oven system to maintain a temperature of 1600 ^{0} C inside the oven surrounding the ceramic composite specimen. The custom made Instron grips were cooled by chilled water, and this chilled water coolant system for the grips was commissioned with success. The custom made high temperature Instron extensometer was also mounted on the load frame. Ceramic rods attached to the extensometer were cooled by compressed air. The Instron load frame was aligned and the high temperature extensometer was calibrated. A tension test was run at 1600 ^{0} C with success but no data were recorded as this was a dummy test performed to check the proper functioning of the complete experimental setup.

A Lab View© program was written to calculate the area under the hysteresis loop of the stress/strain curve during cyclic loading of the specimen with the help of Dan Di Carlo [8]. Electronic signals from the load cell and the stroke or strain measurement were directly input to the data acquisition board to calculate the area under the stress/strain hysteresis loop in quasi-real time which could then be displayed on the screen. The area under the hysteresis loop can be used potentially as a parameter to monitor damage at elevated temperature testing of ceramic composites. A dummy cyclic test with an aluminum specimen at room temperature was run to verify the Lab View© program.

The dynamic stiffness is also calculated from these signals (load and stroke/strain signals) throughout the test and can also be used as a potential damage parameter. The results of these dummy room temperature tests are not reported here as an aluminum specimen was used instead of a ceramic composite. The main objective of this dummy test was to verify the proper execution of the Lab View© program.

A short feasibility study to assess the capability of the acousto-ultrasonic (AU) technique to monitor damage at elevated temperature was performed with the help of laser based detection of stress waves. The Ometron equipment used to perform this test is owned by the Structural Integrity Branch, NASA Lewis Research Center. Previous room temperature tension tests on SiC/CAS-II ceramic composites have shown that the acoustic emission (AE) signals generated due to fiber fracture and matrix cracking are predominantly in the 0.5 to 3 MHz frequency range. Unfortunately, the laser based Ometron equipment is not sensitive in this range, and, hence, given the resources at hand, it was not feasible to detect AE signals with the help of the laser based Ometron equipment [9]. Specialized equipment, specifically designed to suit this application (laser based detection of stress wave sensitive in the 0.5 to 3 MHz frequency range) is needed so as to determine the viability of the AU technique to monitor damage at elevated temperature.

Another NDE tool, Stress Pattern Analysis by Thermal Emission (SPATE) is available at Virginia Tech. This commercially available instrument uses the difference in infrared emission resulting from dynamic volumetric strain variation to measure local values of strain (stress) fields in a solid. We used this instrument in an attempt also to monitor damage at elevated temperature. The results were not conclusive as the equipment appeared to be insensitive to damage growth at elevated temperature.

Recommendations

Amongst the presently available NDE tools, hysteresis loop and dynamic stiffness appear promising in terms of their ability to detect and monitor damage in ceramic composites at elevated temperatures. A refined system for laser based detection of AE stress waves should be obtained, specially designed for elevated temperature testing, that can detect stress waves in the frequency range of 0.5 to 3 MHz. The acousto-ultrasonic technique has been successfully applied to monitor damage at room temperature under dynamic loads with the help of piezoelectric transducers. The next logical step would be to use laser based generation and detection of stress waves to monitor the damage progression during loading in the AU configuration at elevated temperatures.

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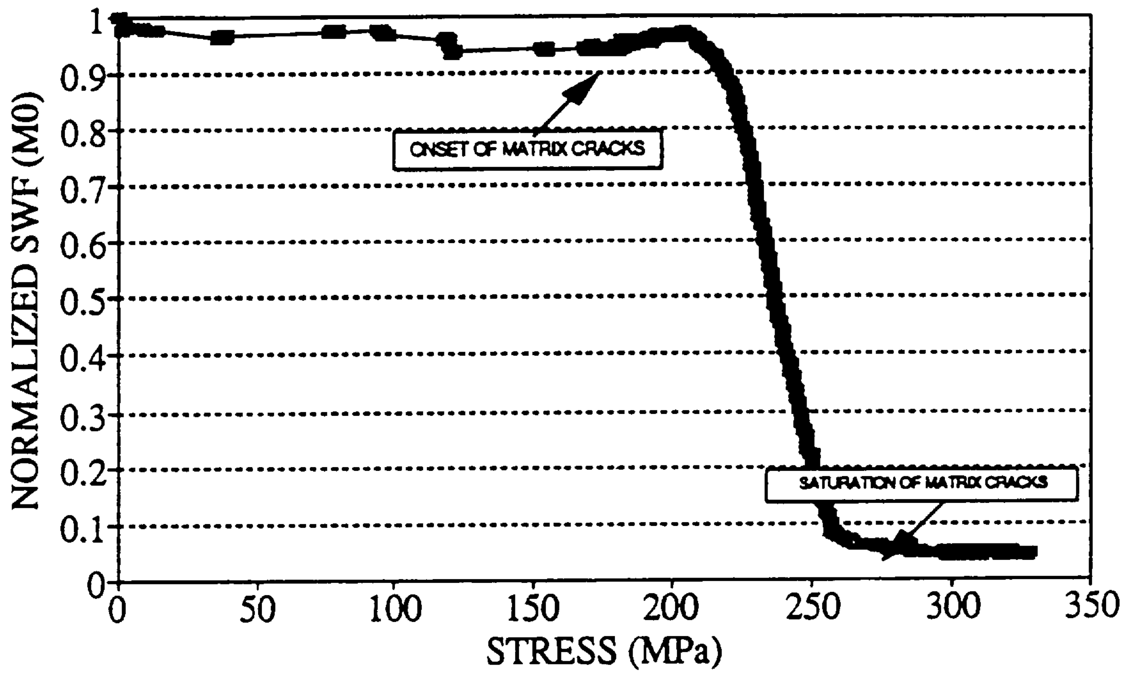

Fig. 1 Normalized SWF(M0) vs stress for sample U2 (SiC/CAS $[0_8]_s$ unidirectional ceramic composite).

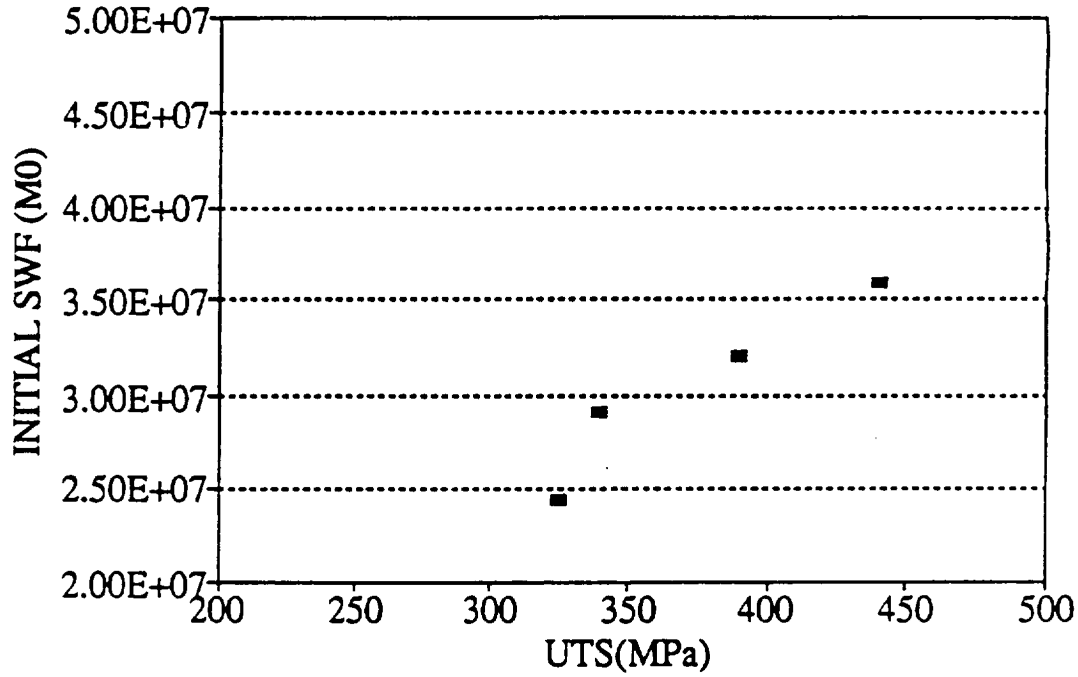

Fig. 2 Initial SWF (M0) vs ultimate tensile strength of unidirectional SiC/CAS $[0_8]_s$ ceramic composite.

Fig. 3 Etched sample of unidirectional SiC/CAS $[0]_{8s}$ ceramic composite (loaded till saturation of matrix cracks).

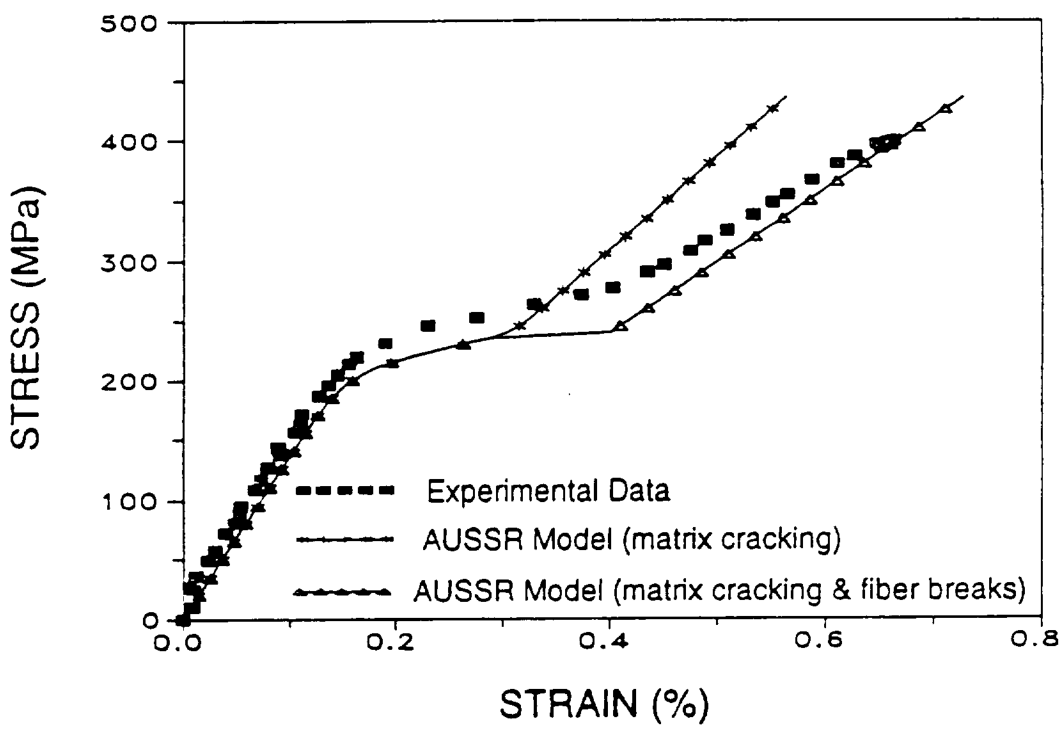

Fig. 4 AUSSR model predictions and experimental stress-strain curve for unidirectional SiC/CAS $[0]_{8s}$ ceramic composite.

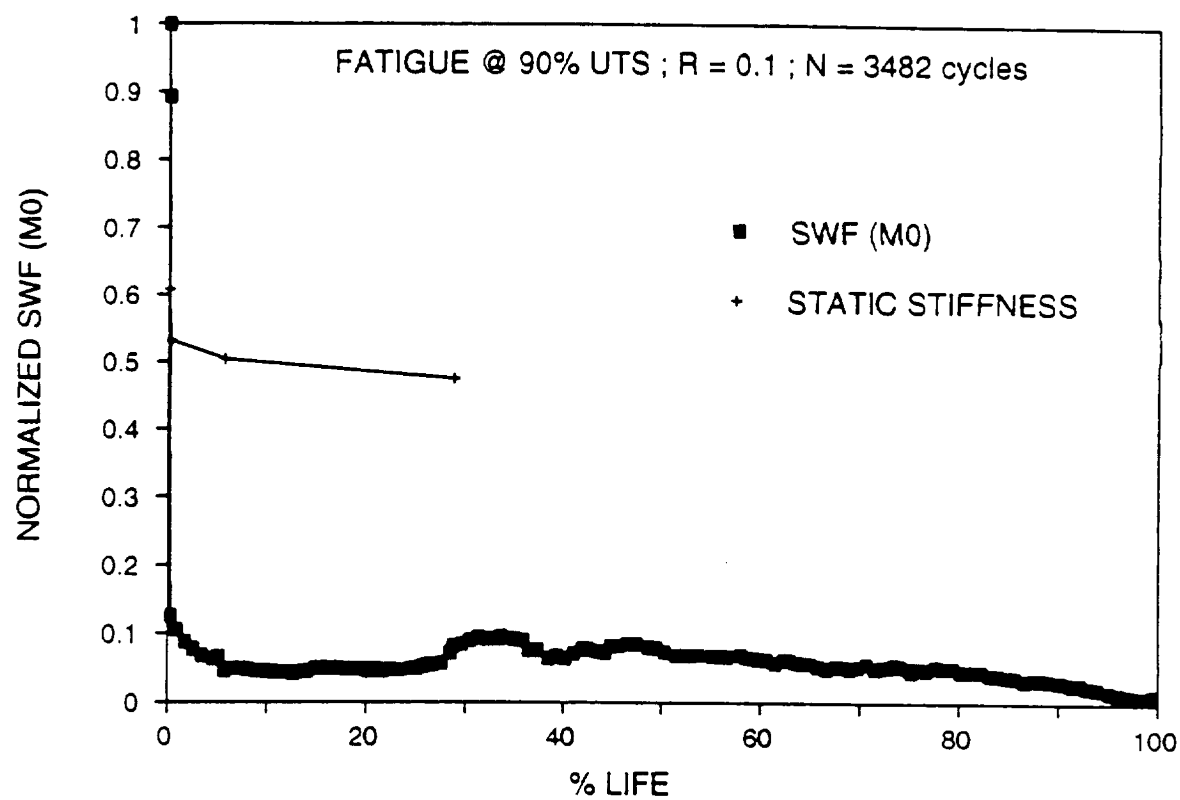

Fig. 5 Normalized SWF (M0) and normalized static stiffness vs % life for sample C12, SiC/CAS $[0/90]_{4s}$ ceramic composite.

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13. ABSTRACT *(Maximum 200 words)*

Custom made ovens were integrated with Instron type load frame to test ceramic matrix composites at 1600 degrees Celsius. A Lab View program was written to monitor the area under the histeresis loop to evaluate damage progression in composites at elevated temperatures. Dynamic stiffness was also calculated throughout the test and used as a damage parameter. It was demonstrated that acoustic emission signals with 0.5 to 3 MHz in frequency are generated due to fiber fracture and matrix cracking in SiC/CAS-II. This damage was beyond the detection capabilities of stress waves by a laser based Ometron system and a stress pattern analysis by thermal emission (SPATE) approach. It was concluded that 1) hysteresis loop and dynamic stiffness can be used to monitor damage in ceramic matrix composites at elevated temperatures, and 2) more work is needed to establish laser-based acousto-ultrasonic for damage monitoring during high temperature loading of ceramic composites.

14. SUBJECT TERMS

NDE; Acousto-ultrasonics; Ceramic composites; Damage monitoring; SiC/CAS

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